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पावर इलैक्ट्रानिकी संधारित्र

Indian Standard

POWER ELECTRONICS CAPACITORS

UDC 621·319·4·016·2 : 621·38

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BUREAU OF INDIAN STANDARDS
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NEW DELHI 110002

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Power Capacitors Sectional Committee, ET 29

CONTENTS

Page No.

SECTION 1 — GENERAL

1 Scope 1
2 Referred Standards 1
3 Terminology 1
4 Service Condition 3

SECTION 2 — QUALITY REQUIREMENTS AND TESTS

5 Test Requirements 4
6 Classification of Tests 4
7 Capacitance and Tan δ Measurements (Routine Tests) 5
8 Capacitor Loss Tangent (Tan δ) Measurement (Type Test) ... 5
9 Voltage Test Between Terminals 5
10 AC Voltage Test Between Terminals and Container 6
11 Test of Internal Discharge Device 6
12 Sealing Test 6
13 Surge Discharge Test 6
14 Thermal Stability Test 6
15 Self-Healing Test (*under consideration*) 7
16 Resonance Frequency Measurement 7
17 Climatic Tests 7
18 Mechanical Test 7
19 Endurance Test (*under consideration*) 7

SECTION 3 — OVERLOADS

20 Maximum Permissible Voltage 7

SECTION 4 — SAFETY REQUIREMENTS

21 Discharge Device 8
22 Container Connections (To Carry Fault Current) 8
23 Protection of the Environment 8
24 Other Safety Requirements 8

SECTION 5 — MARKINGS

25 Marking of the Units 8

SECTION 6 — GUIDE TO INSTALLATION AND OPERATION

26 General 9
27 Choice of the Rated Voltage 9
28 Operating Temperature 9
29 Special Service Conditions 11
30 Overvoltages 11
31 Overload Currents 11
32 Switching and Protective Devices 12
33 Connections 12
34 Choice of Creepage Distance 12
35 Parallel Connections of Capacitors 12
36 Series Connections of Capacitors 12
37 Magnetic Losses and Eddy Currents 12
ANNEX A 13
ANNEX B 14
ANNEX C 16
ANNEX D 17
ANNEX E 18

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Power Capacitors Sectional Committee had been approved by the Electrotechnical Division Council.

(*Continued on third cover*)

Indian Standard
POWER ELECTRONICS CAPACITORS

SECTION 1 — GENERAL

1 SCOPE

1.1 This standard applies to capacitors intended to be used in power electronic equipment, particularly for: (a) Semiconductor switching and protection, and (b) filtering (*see* Note 2).

1.1.1 The rated voltage of these capacitors is limited to 10 000 V. The basic frequency of the systems in which these capacitors are used is usually below 1 000 Hz, while the pulse frequencies may go up to several 1 000 Hz and in some cases beyond 10 000 Hz.

1.1.2 This standard distinguishes ac capacitors and dc capacitors and are considered as components housed in closed cabinets.

NOTES

1 The requirements for capacitors, protected by internal fuses and internal disconnecting devices, as well as requirements for self-healing tests, endurance tests and destruction tests are covered separately in IS 13580 : 1992 and IS 13341 : 1992.

2 This standard covers an extremely wide rage of capacitor technologies for numerous applications. Examples are given in Section 6.

2 REFERENCES

2.1 The list of referred standards is given in Annex A and form adjunct to this standard.

3 TERMINOLOGY

3.1 Capacitor Element (or Element)

An indivisible part of a capacitor consisting of two electrodes separated by a dielectric.

3.2 Capacitor Unit (or Unit)

An assembly of one or more capacitor elements in the same container with terminals brought out.

3.3 Capacitor Bank

An assembly of two or more capacitor units, electrically connected to each other.

3.4 Capacitor

A general term used when it is not necessary to state whether reference is made to an element, a unit or a capacitor bank.

3.5 Capacitor Equipment

An assembly of capacitor units and their accessories intended for connection to a network.

3.6 Power Electronic Capacitor

A power capacitor intended to be used in power electronic equipment and capable of operating continuously under non-sinusoidal current or voltage.

3.7 Metal-Foil Capacitor (Non Self-Healing)

A capacitor in which the electrodes usually consist of metal foils separated by a dielectric, in the event of breakdown of the dielectric, the capacitor does not restore itself.

3.8 Self-Healing Metallized Dielectric Capacitor

A capacitor, the electrodes of which are deposited on the dielectric (usually by evaporation); in the event of breakdown of the dielectric, the capacitor restores itself.

3.9 AC Capacitor

A capacitor essentially designed for operation with alternating voltage.

NOTE — AC capacitors may be used with dc voltage up to the rated voltage only by permission of the capacitor manufacturer.

3.10 DC Capacitor

A capacitor essentially designed for operation with direct voltage.

NOTE — DC capacitors may be used with ac voltage only by permission of the capacitor manufacturer.

3.11 Model Capacitor

A smaller unit which simulates a complete unit or element in an electrical test, without reducing the severity of the electrical, thermal or mechanical conditions.

NOTE — The sum of stresses should always be considered, for instance the sum of temperature, mechanical conditions and electrical stresses.

3.12 Internal (Element) Fuse

A device incorporated in the capacitor which disconnects an element or a group of elements in the event of breakdown.

3.13 Overpressure Disconnector

A disconnecting device designed to interrupt the current path in the case of abnormal increase of the internal pressure.

3.14 Internal Discharge Device

A device incorporated in the capacitor connecting the terminals of the unit, capable of reducing the residual voltage effectively to zero after the capacitor has been disconnected from the supply.

3.15 Rated ac Voltage (U_N)

The maximum operating peak recurrent voltage of either polarity of a reversing type waveform for which the capacitor has been designed.

NOTES

1 The waveform can have many shapes — An example is given in Annex B.

2 The mean value of the waveform may be positive or negative.

3 It is important to note that the nominal voltage is not a rms value.

3.16 Rated dc Voltage (U_N)

The maximum operating peak voltage of either polarity but of a non reversing type wave form, for which the capacitor has been designed, for continuous operation.

3.17 Ripple Voltage (u_r)

The peak-to-peak alternating component of the unidirectional voltage.

3.18 Non-recurrent Surge Voltage (U_S)

A peak voltage induced by a switching or any other disturbance of the system which is allowed for a limited number of times and for durations shorter than the basic period.

3.19 Insulation Voltage (U_I)

The rms rated value of the insulation voltage of capacitive elements and terminals to case or earth. If not specified, the rms value of the insulating voltage is equivalent to the rated voltage divided by $\sqrt{2}$.

3.20 Maximum Peak Current (i)

The maximum current amplitude which occurs instantaneously during continuous operation.

3.21 Maximum Current (I_{max})

The maximum rms current for continuous operation.

3.22 Maximum Surge Current (i_S)

The admissible peak current induced by a switching or any other disturbance of the system which is allowed for a limited number of times.

3.23 Pulse Frequency (f_p)

The repetition rate of periodic current pulses.

3.24 Current Pulse Width (τ)

The time of current flow during the charging or discharging from one voltage value to another, of the capacitor.

NOTE — The pulse current waveform example are shown in Annex B.

3.25 Resonance Frequency (f_r)

The lowest frequency at which the impedance of the capacitor becomes minimum.

3.26 Duty Cycle

3.26.1 *Continuous Duty*

Operation time such that a capacitor is at thermal equilibrium for most of the time.

3.26.2 *Intermittent Duty*

Discontinuous working or operation with variable loads which should be described in terms of ON/OFF or HIGH/LOW periods with their durations.

3.27 Operating Temperature

The temperature of the hottest point on the case of the capacitor in thermal equilibrium.

3.28 Lowest Operating Temperature (θ_{min})

The lowest temperature at which the capacitor may be energized.

3.29 Container Temperature Rise ($\Delta\theta_{case}$)

The difference between the temperature of the hottest point of the container and the temperature of the cooling air.

3.30 Cooling-Air Temperature (θ_{amb})

The temperature of the cooling air measured at the hottest position in the bank, under steady-state conditions, midway between two units. If only one unit is involved, it is the temperature measured at a point approximately 0·1 m away from the capacitor container and at two-thirds of the height from its base.

3.31 Maximum Operating Temperature (θ_{max})

The highest temperature of the case at which the capacitor may be operated.

3.32 Steady-State Condition

Thermal equilibrium attained by the capacitor at constant output and at constant cooling-air temperature.

3.33 Capacitor Losses

The active power consumed by a capacitor.

NOTES

1 Unless otherwise stated, the capacitor, losses will be understood to include losses in fuses and discharge resistors forming an integral part of the capacitor.

2 At high frequency the capacitor losses are predominantly due to losses in connections, contacts, and electrodes.

3.34 Tangent of the Loss Angle (tan δ) of a Capacitor

The ratio between the equivalent series resistance and the capacitive reactance of a capacitor at specified sinusoidal alternating voltage and frequency.

3.35 Equivalent Series Resistance of a Capacitor

An effective resistance which, if connected in series with an ideal capacitor of capacitance value equal to that of the capacitor in question, would have a power loss equal to the active power dissipated in that capacitor under specified operating conditions.

3.36 Maximum Loss Power (P_{max})

The maximum loss power with which the capacitor may be loaded at the maximum case temperature.

4 SERVICE CONDITION

4.1 Normal Service Conditions

This standard gives requirements for capacitors intended for use in the following conditions.

4.1.1 *Altitude*

Not exceeding 1 000 m.

NOTE — The effect of altitude on convection cooling and external insulation should be taken into consideration, if the altitude excess 1 000 m.

4.1.2 *Operating Temperature with Natural Air Cooling*

Capacitors are characterized by both:

a) the lowest operating temperature at which the capacitor may be energized chosen from the three preferred values – 40°C, – 25°C, and – 10°C.

b) and its upper limit of case temperature at which the capacitor may be operated, chosen the values 55°C, 70°C, and 85°C.

4.1.3 *Operating Temperature with Forced Cooling*

If the capacitors are intended for forced cooling with a fluid medium, the operating temperature conditions specified in **4.1.2** shall be observed. Table 1 of preferred maximum temperatures of the cooling fluid shall be applied. The lowest temperature for water cooling may be 5°C.

Table 1 Maximum Temperature (°C) of the Cooling Medium for Unlimited Time

(*Clause* 4.1.3)

Inlet Temperature	Outlet Temperature
35	40
45	50
55	60

4.1.3.1 There are two methods of specifying the upper temperature limit of the cooling medium using either the inlet temperature or the outlet temperature. Unless otherwise agreed, the choice of the method shall be left to the capacitor manufacturer. For the inlet method the flow of the cooling medium must be specified.

4.1.4 This recommendation applies to capacitors intended for use in power electronic equipment and which are hence considered as components of such equipment.

For instance: semiconductor converters and power converters for electric traction. They are generally located in compartments but forced air cooling may expose them to outdoor air conditions (that is, low temperatures, high humidity and pollution).

4.2 Unusual Service Condition

4.2.1 This standard does not apply to capacitors whose service conditions are such as to be in general incompatible with its requirements, unless otherwise agreed between the manufacturer and the purchaser.

4.2.1.1 Unusual service conditions require additional measurements which ensure that the conditions of this standard are complied with even under these unusual service conditions.

4.2.1.2 If such unusual service conditions exist, then they must be notified to the manufacturer of the capacitor. Such unusual service conditions are:

i) unusual mechanical shocks and vibrations,

ii) cooling water with corrosive or obstructing particles (sea water, very hard water),

iii) corrosive and abrasive particles in the cooling air,

iv) conducting dust in the cooling air,

v) oil or water vapour or corrosive substances,

vi) explosive gas or dust,

vii) radioactivity,

viii) unusual storage or transport temperature,

ix) unusual humidity (tropical or subtropical region),

x) excessive and rapid changes of temperature (more than 5°C per hour) or of humidity (more than 5 percent per hour),

xi) service areas higher than 1 000 m above sea level,

xii) superimposed radiofrequency voltages, and

xiii) excessive overvoltage, as far as they exceed the limits given in section three.

SECTION 2 — QUALITY REQUIREMENTS AND TESTS

5 TEST REQUIREMENTS

5.1 General

This section gives the test requirements for capacitor units. Supporting insulators, switches, instrument transformers and other components of capacitor banks or capacitor equipment shall comply with the relevant Indian Standards.

5.2 Test Conditions

5.2.1 Unless otherwise specified for a particular test or measurement, the temperature of the capacitor dielectric shall be in the + 5°C to +35°C range.

5.2.2 If corrections are necessary, the reference temperature shall be +20°C, unless otherwise agreed between the manufacturer and the purchaser.

NOTE — It may be assumed that the dielectric temperature is the same as the ambient temperature, provided that the capacitor has been left in an unenergized state in ac constant ambient temperature for an adequate period.

5.2.3 The ac tests and measurements shall be carried out with sinusoidal voltage of 50 or 60 Hz unless otherwise specified.

6 CLASSIFICATION OF TESTS

6.0 The tests are classified as type test, routine tests and acceptance tests.

6.1 Routine Tests

The sequence of the tests is as indicated:

a) External inspection (*see* **18.1**);

b) Voltage test between terminals (*see* **9.1**);

c) Voltage test between terminals and case (*see* **10.1**);

d) Capacitance and tan δ measurement (*see* **7**);

e) Test of internal discharge device (*see* **11**);

f) Sealing test (*see* **12**).

6.1.1 *Routine tests shall* have been carried out by the manufacturer on every capacitor before delivery. At his request, the purchaser shall be supplied with a certificate detailing the results of such tests.

6.2 Type Tests

Type tests are intended to prove the soundness of the design of the capacitor and its suitability for operation under the conditions detailed in this standard. Unless otherwise specified, every capacitor sample to which it is intended to apply the type test shall first have withstood *satisfactorily the application of all the routine* tests.

6.2.1 Type tests are:

a) Mechanical test (*see* **18**);

b) Voltage test between terminals (*see* **9.2**);

c) Voltage test between terminals and container (*see* **10.2**);

d) Surge discharge test (*see* **13**);

e) Self-healing test (*under consideration*);

f) Climatic tests (*see* **17**);

g) Capacitor tangent of loss angle (tan δ) measurement (*see* **8**);

h) Thermal *stability test* (*see* **14**);

j) Test of internal discharge device (*see* **11**);

k) Resonance frequency measurement (*see* **16**);

m) Endurance test terminal to terminal (*under consideration*).

6.2.2 The type tests shall have been carried out by the manufacturer, and the purchaser shall, on request, be supplied with a certificate, detailing the results of such tests.

6.2.3 These tests shall have been made upon a capacitor, of a design identical with that of the capacitor under contract, or on a capacitor of a design that gives during the test the same or more severe test conditions.

It is not essential that all type tests be carried out on the same capacitor sample.

6.3 Acceptance Tests

The following shall constitute the acceptance tests to be carried out by the manufacturer in connection with any contract by agreement with the purchaser:

a) External inspection (*see* **18.1**);

b) Voltage tests between terminals (*see* **9.1**);

c) Voltage test between terminals and case (*see* **10.1**);

d) Capacitance and tan δ measurement (*see* **7**);

e) Test of internal discharge device (*see* **11**);

f) Sealing test (*see* **12**); and

g) Surge discharge test (*see* **13**).

6.3.1 For carrying out acceptance tests specified in the standard, the sampling procedure given in Annex E shall be followed.

7 CAPACITANCE AND TAN δ MEASUREMENTS (ROUTINE TEST)

7.1 Measuring Procedure

The capacitance and tan δ shall be measured at a voltage and at a frequency chosen by the manufacturer. The method used shall not include errors due to harmonics or to accessories external to the capacitor to be measured, such as reactors and blocking circuits in the measuring circuit. The accuracy of the measuring method shall be given and shall be better than 1 percent for capacitance and $\pm 1 \cdot 10^{-4}$ (± 10 percent) for tan δ if the measurement is made at 50-60 Hz.

7.1.1 The capacitance measurements shall be carried out after the voltage test between terminals (*see* **9**). For capacitors with internal fuses, these measurements shall also be made before the voltage tests.

NOTE — The tan δ measurement shall be carried out by sampling when the number of capacitors to test is particularly large.

7.2 Capacitance Tolerances

If not otherwise specified, the capacitance measured shall not differ from the rated capacitance by more than − 10 percent to + 10 percent for capacitors.

7.3 Loss Requirements (tan δ)

The requirements regarding capacitor losses may be agreed upon between the manufacturer and the purchaser.

NOTE — The manufacturer should, on agreement, furnish curves or tables showing the capacitor losses under steady-state conditions at rated output as a function of ambient temperature within the temperature category.

8 CAPACITOR LOSS TANGENT (TAN δ) MEASUREMENT (TYPE TEST)

8.1 AC Capacitors

The capacitor losses (tan δ) shall be measured at the end of the thermal stability test (*see* **14**). The measuring voltage shall be that of the thermal stability test and a frequency in the range of 50 to 120 Hz.

8.2 DC Capacitors

The measurement shall be carried out with a frequency in the range of 50 to 120 Hz and at ripple voltage (U_r) divided by $2\sqrt{2}$.

NOTE — The losses in the electrodes, connections, leads and terminals are functions of the frequency and can be calculated.

8.3 Loss Requirements

The value of tan δ measured in accordance with **8.1** and **8.2** shall not exceed 0·003.

9 VOLTAGE TEST BETWEEN TERMINALS

9.1 Routine Test

Every capacitor shall be subjected for 10s to either test given in Table 2. The choice is left to the manufacturer. During the test, neither puncture nor flashover shall occur, self-healing breakdowns are permitted. In the case of units with all elements in parallel, operation of internal element fuse(s) is permitted, provided the capacitance tolerances are still met.

9.2 Type Test

The capacitor shall be subjected for 1 min to either test given in Table 2. The choice is left to the manufacturer.

NOTES

1 The duration may be reduced to 2 s provided the voltage is increased by 10 percent.

2 The ac test voltage frequency may be 50 or 60 Hz.

3 The test voltage indicated in Table 2 can be reduced if capacitors are intended for intermittent duty (*see* **3.26**) or for short service duration; the new values shall be agreed upon between the manufacturer and the purchaser.

Table 2 Test Voltage Between Terminals

(*Clauses* 9.1 *and* 9.2)

	AC Capacitors		DC Capacitors	
	Non Self-healing	Self-healing	Non Self-healing	Self-healing
AC test voltage rms value	$1 \cdot 5\ U_n$	$1 \cdot 25\ U_n$	—	–
DC test voltage	$2 \cdot 15\ U_n$	$1 \cdot 75\ U_n$	$2\ U_n$	$1 \cdot 5\ U_n$

10 AC VOLTAGE TEST BETWEEN TERMINALS AND CONTAINER

10.1 Routine Test

Units having all terminals insulated from the container shall be subjected for 10 s to a voltage test applied between the terminals (joined together) and the container. Units having one terminal permanently connected to the container shall not be subjected to this test.

10.1.1 The test voltage values are the following:

$U_{t\_case} = 2U_i + 1\,000$ V or 2 000 V whichever is the higher value where U_i is the insulation voltage.

10.1.2 The insulation voltage of the capacitor shall be specified by the user. The insulating voltage is equal to the nominal voltage of the capacitor, divided by 2, unless otherwise specified.

10.1.3 During the test, neither puncture nor flashover shall occur. The test shall be performed, even if one of the terminals is intended to be connected to the container in service.

10.2 Type Test

Units having all terminals insulated from the container shall be subjected to a test according to **10.1** with the same value of the voltage, but with a duration of 1 min.

11 TEST OF INTERNAL DISCHARGE DEVICE

11.1 The resistance of the internal discharge device, if any, shall be checked either by a resistance measurement or by measuring the self-discharging rate. The test shall be made after the voltage tests of **9**.

12 SEALING TEST

12.1 Unenergized capacitor units shall be heated to a uniform temperature of at least their maximum operating temperature plus 5°C and shall be maintained at this temperature for 2 h. No leakage shall occur. It is recommended that a suitable indicator be used.

NOTE — If the capacitor contains no liquid materials the choice of the test method is left to the manufacturer, and shall be carried out by sampling.

13 SURGE DISCHARGE TEST

13.1 The units shall be charged by means of dc and then discharged through a gap situated as close as possible to the capacitor. They shall be subjected to five such discharges within 10 min. The test voltage shall be equal to $1 \cdot 1\ U_N$. Within 5 min after this test, the unit shall be subjected to a voltage test between terminals (*see* **9**).

13.2 The capacitance shall be measured before the discharge test and after the voltage test. The measurement shall not differ by an amount corresponding either to breakdown of an element or to blowing of an internal fuse.

13.3 For self-healing capacitors the change of capacitance shall be less than ±1 percent. The increase of tan δ shall not be greater than 20 percent.

13.4 If however a maximum surge current is specified, the discharge current shall be adjusted by variation of the charging voltage and the impedance of the discharge circuit to a value of:

$$\hat{i}_{test} = 1 \cdot 4 \times \hat{i}_s$$

14 THERMAL STABILITY TEST

14.1 General

This test is performed on both ac and dc capacitors and provides the following information about the capacitors subjected to it:

a) It determines the thermal stability of the capacitor under overload conditions.

b) It conditions the capacitor to enable a reproducible loss measurement to be made.

14.2 Measuring Procedure

One capacitor unit having an output as nearly as possible to rated output shall be placed in an enclosure where the cooling temperature shall be:

a) for natural cooling, that indicated by the manufacturer (θ_{amb}) $+5°C$,

b) for forced cooling, the specified outlet cooling temperature (*see* Table 1) $+5°C$.

14.2.1 After all parts of the capacitor have attained the temperature of the cooling medium, the capacitor shall be subjected for a period of at least 48 h to an ac voltage of substantially sinusoidal form.

The value of the voltage and frequency shall be kept constant throughout the test. The current value shall be $1{\cdot}1\ I_{max}$. The supply conditions are that indicated in Annex C with the power = $1{\cdot}21\ P_{max}$.

14.2.2 During at least 6 h, the temperature of the case near the top shall be measured at least four times. Throughout this period of 6 h, the temperature rise shall not increase by more than 1°C. Should a greater change be observed, the test may be continued until the above requirement is kept for four consecutive measurements during a 6 h period.

14.2.3 Before and after the test, the capacitance shall be measured within the temperature range according to **5.2** for testing and the two measurements shall be corrected to the same dielectric temperature. The difference between the two measurements shall be less than an amount corresponding to either breakdown of an element or operation of an internal fuse. At the end of this test the tan δ measurement is performed (*see* **8.1** and **8.2**).

NOTES

1 When checking whether the capacitor losses or the temperature conditions are satisfied, fluctuations of voltage, frequency and cooling medium temperature during the test shall be taken into account. For this reason, it is advisable to plot these parameters and the case temperature as a function of the time.

2 The test may be performed, by agreement between the manufacturer and the purchaser, with non-sinusoidal voltage provided the values of current and loss power remain : $1{\cdot}1\ I_{max}$ and $1{\cdot}2\ P_{max}$.

15 SELF-HEALING TEST (*under consideration*)

16 RESONANCE FREQUENCY MEASUREMENT

16.1 The resonance frequency shall be measured within the temperature range according to **5.2,** using a method that excludes errors due to connections and due to accessories.

16.2 The measuring method may be chosen, as convenient, from the two examples given in Annex D. The value of the resonance frequency shall not exceed the value agreed upon between the manufacturer and the purchaser. This measurements is not necessary for all applications.

17 CLIMATIC TESTS

17.1 The damp heat test and test with rapid change of temperature are carried out as per current practice described in IS 9000 (Part 4): 1979 and IS 9000 (Part 5/Sec 1 & Sec 2) : 1981.

18 MECHANICAL TESTS

a) Vibration, in accordance with IS 9 000 (Part 8) : 1981.
   i) For capacitors of weight not exceeding 3 kg:

      $f = 10 - 55$ Hz

      $a = \pm\ 0{\cdot}35$ mm

      Test duration per axis = 10 frequency cycles (3 axis offset from each other by 90°), 1 octave per minute.
   ii) For capacitors whose weight exceeds 3 kg: the choice of the test condition is left to the manufacturer.

b) *Impacts*: The choice of the test condition is left to the manufacturer.

18.1 External Inspection

Capacitors are visually examined and checked for finish and marking.

19 ENDURANCE TEST (*under consideration*)

SECTION 3 — OVERLOADS

20 MAXIMUM PERMISSIBLE VOLTAGE

20.1 Capacitor units shall be suitable for operation at voltage levels according to Table 3 (*see also* **29** and **30**).

20.1.1 The amplitudes of the overvoltages that may be tolerated without significant reduction in the life-time of the capacitor depend on their duration, the number of applications and the capacitor temperature. The values given in Table 3 for voltages higher than $1 \cdot 1\ U_N$ are based on no significant reduction in life. Also, these values assume that the overvoltages may appear when the internal temperature of the capacitor is less than 0°C but within the temperature category.

Table 3 Permissible Voltage Levels

(*Clause* 20.1, 20.1.1, 27.3 *and* 30.4)

Over-voltage	Maximum Duration Within One Day	Observation
$1 \cdot 1\ U_N$	30 percent of on-load duration	System regulation
$1 \cdot 15\ U_N$	30 min	
$1 \cdot 2\ U_N$	5 min	
$1 \cdot 3\ U_N$	1 min	System switching
$1 \cdot 5\ U_N$	100 ms	

SECTION 4 — SAFETY REQUIREMENTS

21 DISCHARGE DEVICE

21.1 The use of discharge resistors is not suitable for certain power electronic capacitors. When required by the purchaser, each capacitor unit or bank shall be provided with means for discharging each unit in 3 *min to 75 V or less from an initial direct voltage* U_N. For capacitors *having* U_N *1 000 V the dicharging time shall be 10 min.*

21.2 There must be no switch, fuse, cut-out, or any other isolating device between the capacitor unit and this discharge device.

21.3 A discharge device is not a substitute for short-circuiting the capacitor terminals together and to earth before handling.

NOTES

1 Capacitors connected directly to other electrical-equipment providing a discharge path shall be considered properly discharged, provided that the circuit characteristics are such as to ensure the discharge of the capacitor within the times specified above.

2 Discharge circuit must have adequate current-carrying capacity to discharge the capacitor from the peak of the maximum overvoltage according to **20**.

22 CONTAINER CONNECTIONS (To Carry Fault Current)

22.1 To enable the potential of the metal container of the capacitor to be fixed, and to be able to carry the fault current in the event of a breakdown of the container, the container must be provided with a connection suitable to carry the fault current or with an unpainted non-corrodible metallic region suitable for connecting clamp.

23 PROTECTION OF THE ENVIRONMENT

23.1 When capacitors are impregnated with materials that must not be dispersed into the environment, precautions shall be taken.

23.1.1 The purchaser shall specify any special requirements for labelling (*see* **25.2**).

24 OTHER SAFETY REQUIREMENTS

24.1 The purchaser shall specify at the time of enquiry any special requirements with regard to the safety regulations where capacitor is to be installed.

SECTION 5 — MARKINGS

25 MARKING OF THE UNITS

25.1 Rating Plate

The following information shall be given on the rating plate of each capacitor unit:

i) Name of the manufacturer

ii) Identification number and manufacturing year

The year may be a part of indentification number or be in code form

iii) C = ...μF

iv) T_{ol} = ...%

v) U_N = ...V ac or dc

vi) U_i = ...V ac (if specified, *see* **3.19**)

vii) P_{max} = ...W (optional)

viii) f_2 = ...Hz (optional)

ix) I_{max} = ...A (optional)

x) $\hat{I}_s$ = ...A (if any)

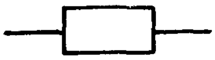
xi) θ_{min} = ...°C

xii) θ_{max} = ...°C

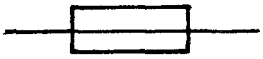
xiii) Type of cooling medium and temperature (only for forced cooling) (*see* **4**).

Reference to this standard.........that is Ref IS 13648 : 1993.

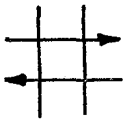
25.1.1 The following signs should be added if applicable:



for internal discharge device



for internal fuse or disconnector



SH for self-healing
or capacitors in alternative

NOTE — For small units where it is impracticable to indicate all the above items on the rating plate, certain items may be stated in an instruction sheet.

25.2 Warning Plate

If the capacitor unit contains material that may pollute the environment or may be hazardous in any other way, the unit shall be provided with a label according to the relevant laws of the country.

25.3 Data Sheet

The data sheet must give values for tan δ as a function of frequency. f_1, f_2 and P_{max} for the evaluation of the losses in the capacitors.

SECTION 6 — GUIDE TO INSTALLATION AND OPERATION

26 GENERAL

26.1 Overstressing and overheating shorten the life of a capacitor, and therefore the operating conditions (that is temperature, voltage and current cooling) should be strictly controlled.

26.1.1 Because of the different types of capacitor and the many factors involved, it is not possible to cover, by simple rules, installation and operation in all possible cases.

26.2 The information in **27** to **37** is given with regard to the more important points to be considered. In addition, the instructions of the manufacturer, the requirements on safety of IE Rules 1956 and power supply authorities must be followed.

26.2.1 There are seven major applications (*see* Table 4):

a) Internal overvoltage protection: snubber capacitors, loaded with parts of sinusoidal voltages; both voltages may alternate with a certain amount of superimposed direct voltage;

b) DC harmonic filter: capacitors, generally loaded with a direct voltage superimposed upon a non-sinusoidal alternating voltage;

c) Switching circuit: commutating capacitors, generally loaded with trapezoidal voltages;

NOTE — Requires very high peak current and rms current capability.

d) External ac overvoltage protection;

e) External dc overvoltage protection;

f) Internal ac harmonic filter; and

g) DC energy storage: supporting capacitors. Generally supplied with direct voltage and periodically charged and discharged with high peak current.

NOTE — The requirements of energy storage capacitors are covered separately in IS 13666 : 1993.

27 CHOICE OF THE RATED VOLTAGE

27.1 The rated voltage of the capacitor shall be equal to the recurrent peak voltage, not so much because of the intrinsic stress, but because the high values of dv/dt in power electronics may induce partial discharge and losses which affect the capacitor life.

27.2 Most of the application in power electronics show varying loads. Therefore it is necessary to discuss the rated voltage and the true voltage stresses extensively between the manufacturer and the user.

27.3 Only in case of emergency should capacitors be operated at maximum permissible voltage and maximum operating temperature simultaneously, and then only for short periods of time (*see* Table 3).

NOTES

1 An excessive safety margin in the choice of the rated voltage U_N should be avoided, because this would result in a decrease of output when compared with the intended output.

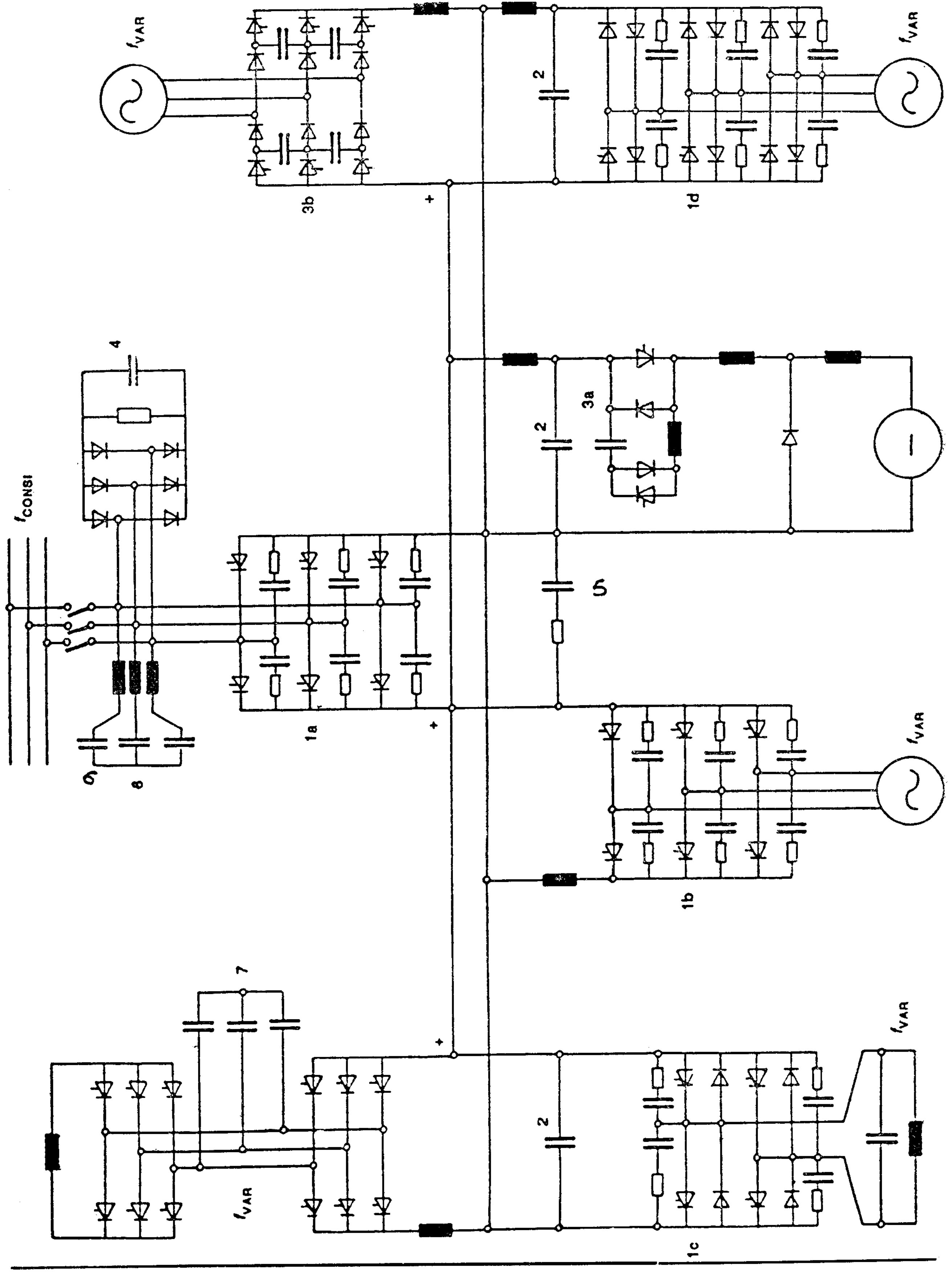
2 The manufacturer may give the diagram of applicable voltage as a function of frequency and ambient temperature (θ_{amb}).

28 OPERATING TEMPERATURE

28.1 Attention should be paid to the operating temperature of the capacitor because this has a great influence on its life. Temperature in excess of θ_{max} accelerates electrochemical degradation of the dielectric. Temperature below θ_{min} or very rapid changes from hot to cold may initiate partial discharge degradation in the dielectric.

Table 4 Schematic Diagram on Application of Capacitor

(*Clause* 26.2.1)



28.2 Installation

Capacitors shall be so placed that there is adequate dissipation by convection and radiation of the heat produced by the capacitor losses. The ventilation of the operating room and the arrangement of the capacitor units shall provide good air circulation around each unit. This is of importance for units mounted in rows one above the other.

28.2.1 The temperature of capacitors subjected to radiation from the sun or from any high temperature surface will be increased. After installation it is necessary to verify that the temperature of the case be lower than θ_{max} with the maximum service conditions (voltage, current and cooling temperature).

28.2.2 Depending on the cooling air temperature, the intensity of the cooling and the intensity and duration of the radiation, it may be necessary to adopt for one of the following remedies:

a) To protect the capacitors from radiation,

b) To choose a capacitor designed for a *higher service air temperature, and*

c) To employ capacitors with rated voltage higher than that laid down in **27**.

Capacitors installed at high altitudes (more than 1 000 m) will be subjected to decrease heat dissipation, which should be considered when determining the power of the units.

28.3 Unusual Cooling Conditions

In exceptional cases, the inlet temperature (*see* Table 1) may be higher than 55°C maximum and capacitors of special design or with a higher rated voltage must be used.

29 SPECIAL SERVICE CONDITIONS

29.1 Apart from high ambient temperature, other adverse conditions of use are liable to be encountered in tropical countries. When the purchaser is aware of such conditions the manufacturer should be informed when the capacitors are ordered.

29.2 This information should also be given to the suppliers of all associated equipment for the capacitors installation. The most important conditions are the following:

a) *Frequent occurrence of periods of high relative humidity*

It may be necessary to use insulators of special design. Attention is drawn to the possibility of external fuses being shunted by a deposit of moisture on their surfaces.

b) *Rapid mould growth*

Metals, ceramic materials and some paints and lacquers do not support mould growth. When fungicidal materials are used, they do not retain their poisoning property for more than several months; in any case, mould may develop in an installation on places where dust etc can settle.

c) *Corrosive atmospheres are found in industrial and coastal areas*

It should be noted that in climates of higher temperature the effects of such atmospheres may be more severe than in temperature climates. Highly corrosive atmospheres may be present even in indoor application.

d) *Attack by insects*

When capacitors are mounted in a location with a high degree of pollution, special precautions shall be taken.

e) *Altitude exceeding 1 000 m*

Capacitors used at altitudes exceeding 1 000 m are subjected to special conditions. The choice of the type should be made by agreement between purchaser and manufacturer (*see* **5.3**).

30 OVERVOLTAGES

30.1 The overvoltage factors are specified in **20**. With the manufacturer's agreement, the overvoltage factor may be increased if the estimated number of overvoltage is lower, or if the temperature conditions are less severe.

30.2 Capacitors that are liable to be subjected to high lightning overvoltages should be adequately protected. If lightning arresters are used, they should be located as near as possible to the capacitors.

30.3 Transient overvoltages during unusual service condition may enforce the choice of higher rated capacitors.

30.4 In railway applications the overvoltages are often higher than that permitted in Table 3.

31 OVERLOAD CURRENTS

31.1 Capacitors should never be operated with currents exceeding the maximum values specified in **3.20**, **3.21** and **3.22**.

31.2 Transient overcurrents of high amplitude and frequency may occur when capacitors are switched into circuit or the equipment is switched. It may be necessary to reduce these transient overcurrents to acceptable values in relation to the capacitor and to the equipment.

31.3 If the capacitors are provided with fuses (internal or external), the peak value of the overcurrents due to switching operations shall be limited to the value of **3.22**.

32 SWITCHING AND PROTECTIVE DEVICES

32.1 The switching and protective devices and the connections shall be capable of withstanding the electrodynamic and thermal stresses caused by the transient overcurrents of high amplitude and frequency that may occur when switching on or otherwise.

32.1.1 When consideration of the electrodynamic and thermal stresses would lead to excessive dimensions, special precautions, for the purpose of protection against overcurrents, should be taken.

NOTE — Fuses, in particular, should be chosen with an adequate thermal capacity.

33 CONNECTIONS

33.1 The current leads into the capacitor are capable of dissipating heat from the capacitor. In the opposite direction they could possibly transfer heat generated in outer connection into the capacitor. Therefore it is necessary to keep the connections leading to the capacitors always cooler than the capacitor itself.

33.2 Any bad contacts in capacitor circuits may give rise to arcing, causing high-frequency oscillations that may overheat and overstress the capacitors. Regular inspection of all capacitor equipment contacts and capacitor connections is therefore recommended.

34 CHOICE OF CREEPAGE DISTANCE

34.1 Bushing, insulators to earth, inter-rack insulators, etc should be in accordance with IS 3716 : 1978.

34.2 Special care has to be taken to ensure that all necessary information on climatic condition and especially rapid changes in humidity have been discussed between manufacturer and user.

35 PARALLEL CONNECTIONS OF CAPACITORS

35.1 Special care is necessary when designing circuits with capacitors connected in parallel, because there are two possible dangers:

a) The current splitting depends on slight differences of resistances and inductances in the current paths, so that one of the capacitors may be easily overloaded.

b) Because of the high frequencies involved with power electronics, interconnections are designed for low inductance and resistance.

35.1.1 In consequence, when one capacitor fails by a short circuit, the complete energy of the bank will be rapidly dissipated at the point of breakdown. Usually, it is impossible to disconnect the units by a current limiting fuse. Special precautions have to be made in this case.

36 SERIES CONNECTIONS OF CAPACITORS

36.1 Because of varying insulation resistances of units, voltage division between units has to be enforced by ohmic voltage dividers for dc loads.

36.2 AC voltage and intermittent dc voltages with long OFF-periods are usually safe, because the voltage drops to zero in this case.

The insulation voltage must thus be given accordingly.

37 MAGNETIC LOSSES AND EDDY CURRENTS

37.1 The strong magnetic fields of conductors in power electronics may induce alternating magnetization of magnetic cases and eddy currents in any metal part and thereby produce heat. Therefore it is necessary firstly to situate capacitors at a safe distance from heavy current conductors and secondly to avoid the use as far as possible of magnetic materials.

ANNEX A

(*Clause* 2.1)

LIST OF REFERRED INDIAN STANDARDS

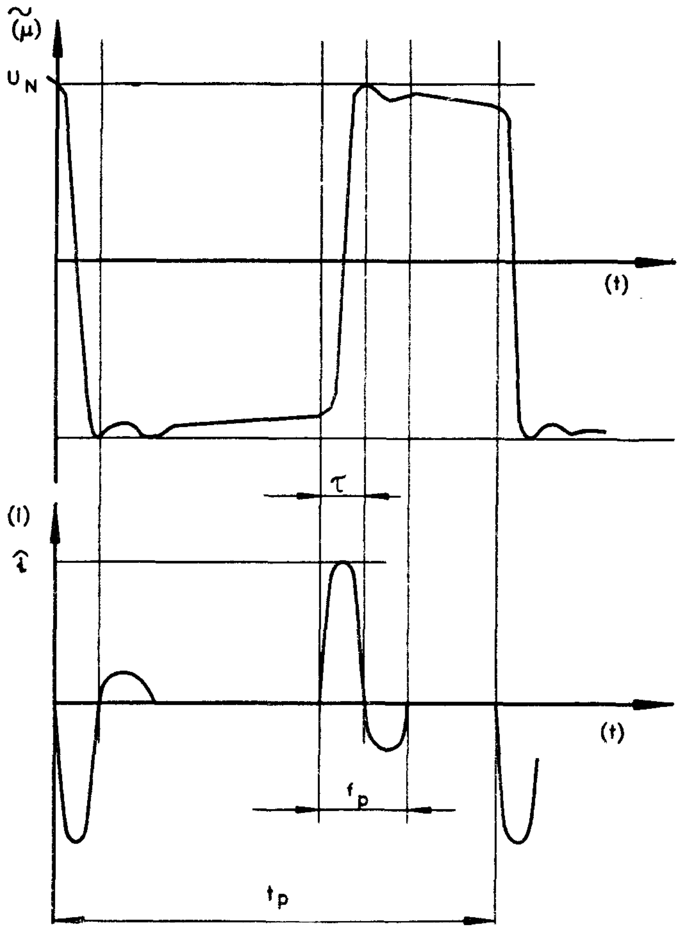
IS No.	*Title*
3716 : 1978	Application guide for insulation coordination (*first revision*)
2500 (Part 1) : 1973	Sampling inspection tables : Part 1 Inspection by attributes and by count of defects (*first revision*)
9 000	Basic environments testing procedures for electronic and electrical items:
(Part 4) : 1979	Part 4 Damp heat (steady state)
(Part 5/Sec 1 and 2) : 1981	Part 5 Damp heat (cyclic) test
(Part 8) : 1981	Part 8 Vibration (sinusoidal) test
13580 : 1992	Internal fuses and internal overpressure disconnector for power electronic capacitors
13341 : 1992	Requirements for ageing test, self-healing test and destruction test on shunt capacitors of the self-healing type for ac power systems having a rated voltage up to and including 650 V.
IS 13666 : 1993	Draft energy storage capacitors

ANNEX B

(*Clauses* 3.15 *and* 3.24)

WAVE FORMS

B-1 For power electronic capacitors the definitions are explained on an example of a trapezoidal voltage.

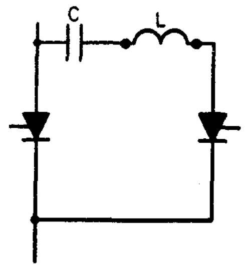


1 A Commutating Waveform

$$f_p = \frac{1}{t_p}$$

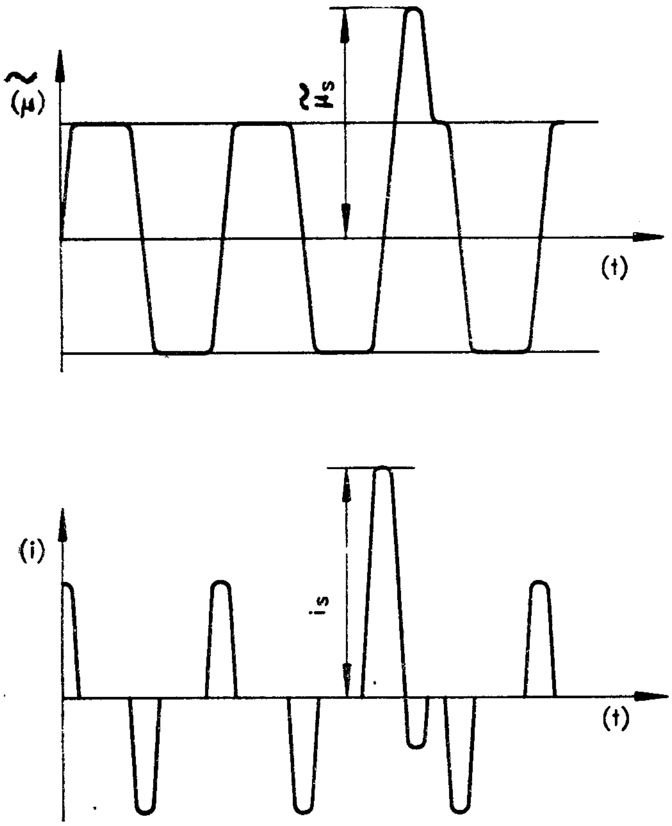
τ = capacitor current pulse width
t_p = system pulse duration
f_p = system pulse frequency
U_n = peak recurrent voltage
$\hat{i}$ = peak current

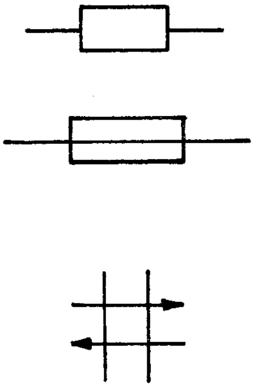
$\tau = \pi\sqrt{L.C}$



1 B Commutating Circuit Example

FIG. 1 COMMUTATING WAVEFORM





$\tilde{\mu}_s$ = Non-recurrent surge voltage
i_s = Surge current

FIG. 2 SURGE WAVE FORM

ANNEX C

(*Clause* 14.2.1)

OPERATIONAL LIMITS OF CAPACITORS WITH SINUSOIDAL VOLTAGES AS A FUNCTION OF FREQUENCY, AND AT MAXIMUM TEMPERATURE (θ_{max})

C-1 The maximum voltage is in general a function of dielectric thickness (a) intrinsic field strength (E_D) and temperature (θ):

$$U_{max} = f(E_D, a, \theta)$$

C-1.1 For the frequency range $f \leq f_1$ is valid:

$$U_{max} = U_N$$

C-1.1.1 f_1 is the frequency at which the loss power of the capacitor is maximum:

$$P_{max} = \frac{U^2_N}{2} \omega \cdot \quad C \tan \delta_1 \qquad \omega = 2\pi f_1$$

C-1.1.2 f_2 is the frequency at which the maximum current (I_{max}) produces the maximum power loss (P_{max}) in the capacitor.

C-2 For the frequency range f_1 to f_2, we have:

$$P_{max} = \text{constant}$$

and f_2 is the frequency at which the effective current reaches its maximum:

$$I = I_{max}$$

C-2.1 Above the maximum frequency the maximum current has to be reduced due to skin effect, etc.

C-3 Now the characteristic values of the capacitor are distinctly recognized:

U_{max} = maximum voltage
P_{max} = maximum loss power
$\tan\delta_1$ = capacitor loss tangent at frequency f_1
$\tan\delta_2$ = capacitor loss tangent at frequency f_2
f_2 = maximum frequency for full loss power and maximum current
I_{max} = maximum current r, m. s. value

NOTE — The suggested thermal stability test conditions (*see* **14**) are:

$$1{\cdot}21\, P_{max} = \frac{U^2}{2} \omega_2\, C.\tan\delta_2 = 1{\cdot}21\, \frac{I^2_{max}}{\omega_2 C}$$

$$\tan\delta_2\ \omega_2 = 2\pi f_2$$

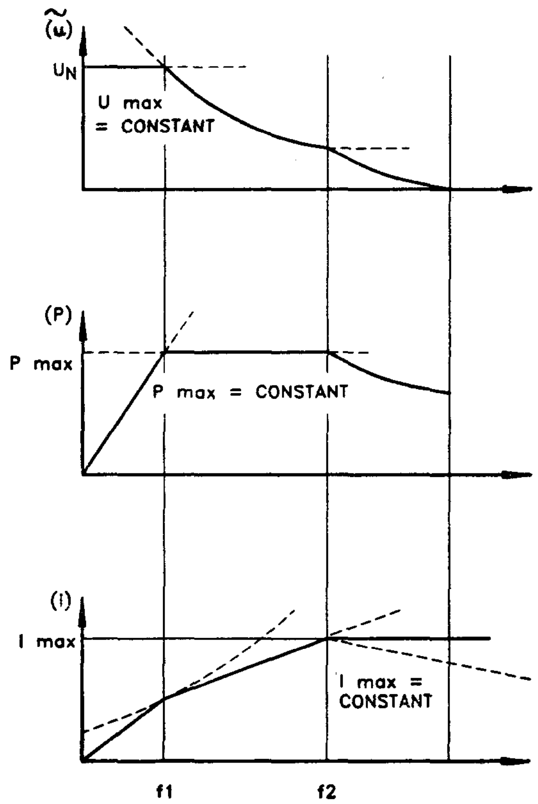


FIG. 3 OPERATION LIMITS OF CAPACITORS

ANNEX D

(*Clause* 16.2)

RESONANCE FREQUENCY MEASURING METHODS

D-1 METHOD I

D-1.1 The measuring circuit is given in Fig. 4.

D-1.2 By changing a frequency and keeping U_1 constant, it is possible to plot a graph which shows the relation between the voltage across the capacitor and supply frequency.

D-1.3 The shape of this graph is shown in Fig. 5. The minimum value of U_2 corresponds to the resonance frequency (f_r). The connections must be as short as possible.

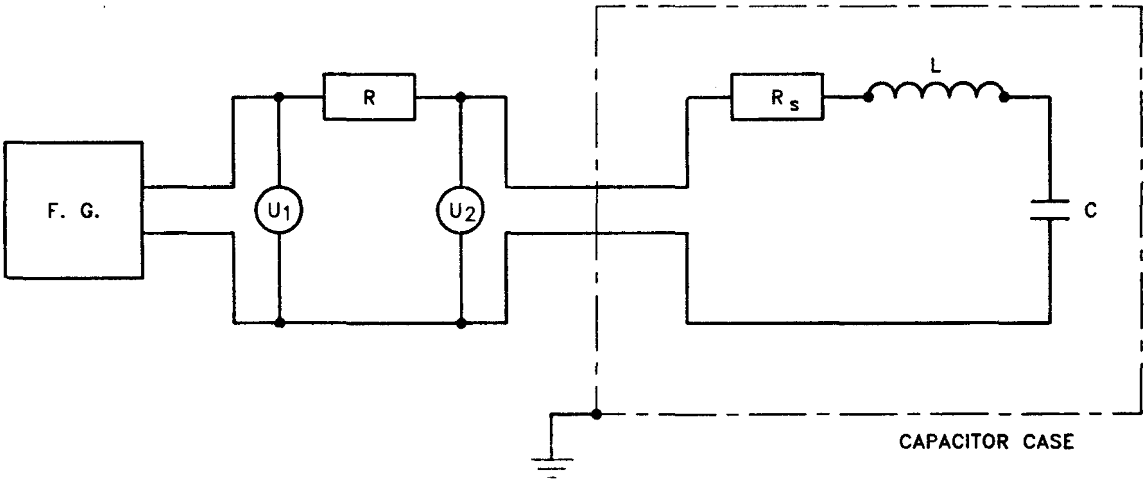
D-2 METHOD II

D-2.1 The unit shall be charged by means of dc and then discharged through a gap situated directly at the capacitor terminals.

D-2.2 The discharage current wave shape (*see* Fig. 6) is recorded by a cathode ray oscilloscope. f_r is evaluated by computation of the number of intersections of the time axis.

D-2.2.1 The shape of the discharge waveform is a function of the equivalent series resistance and stray inductance.

NOTE — With the second method (*see* **D-2**) the discharge frequency is measured, that is equal to self resonance frequency if the damping factor is low and external inductance of the connections is negligible in comparison with that of internal connections.



where F. G. = Variable frequency generator

R = Load resistance (non inductive directly connected to the tested capacitor terminals)

R_s = Capacitor equivalent series resistance

L = Capacitor stray inductance

C = Capacitor capacitance

U_1, U_2 = Electronic voltmeters

FIG. 4 MEASURING CIRCUIT

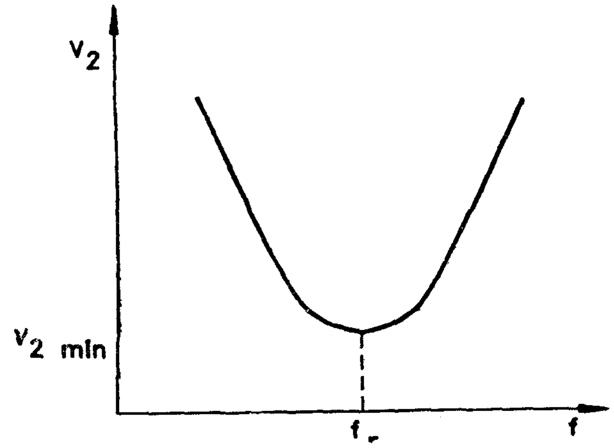


FIG. 5 RELATIONSHIP OF FREQUENCY VERSUS VOLTAGE

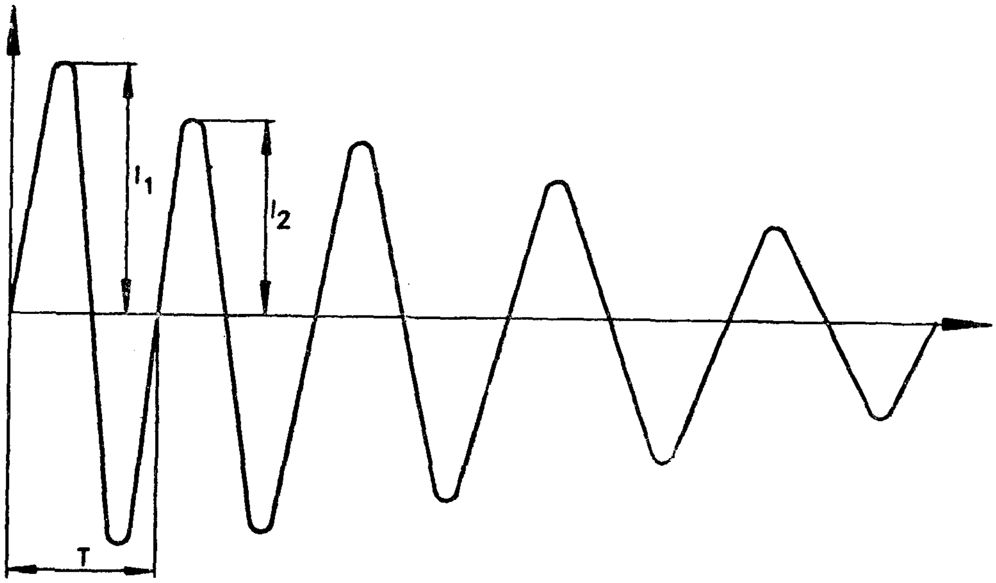


FIG. 6 DISCHARGE CURRENT WAVE SHAPE ON CRO

ANNEX E

(*Clause* 6.3.1)

SAMPLING PLAN FOR ACCEPTANCE TESTS

E-1 LOT

In a consignment all the power electronic capacitors of the same rating manufactured from the same material under similar conditions of production shall be grouped together to constitute a lot.

E-2 SAMPLE SIZE AND CRITERIA FOR CONFORMITY

Unless otherwise agreed to between the supplier and the purchaser, the procedure given in IS 2500 (Part 1) : 1973 shall be followed for sampling inspection. For this purpose a single sampling plan with inspection level IV and AQL of 2·5 percent given in Tables 1 and 2 of IS 2500 (Part 1) : 1973 shall be followed for all the acceptance tests.

(*Continued from second cover*)

This standard provides the following on the power electronic capacitors:

a) Uniform rules regarding performance, test and rating;
b) Specific safety rules; and
c) Guidance for installation and operation.

The power electronic capacitors are used in:

a) semi-conductor switching and protection; and
b) filtering circuits and energy storage.

In the equipments rated up to 10 000 V and power frequency below 1 000 Hz. However, the pulse frequency in the circuit may be higher than 1 000 Hz (*see* **1.1.1**).

NOTE — The requirements of energy strorage capacitors are covered separately in IS 13666 : 1993.

This standard is in line with IEC Pub 1071-1 (1991) — 'Power Electronic Capacitors — Part 1 General', issued by the International Electrotechnical Commission.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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